Has chaos theory found any useful application in the social sciences?

Overview: It has been more than 10 years since ideas from deterministic chaos began appearing in the social science literature. This interdisciplinary spread of ideas was accompanied by expectations that many major problems in the social sciences could be easily 'solved' using chaos-inspired techniques. It is probably true that many early expectations for chaos were not fulfilled. Its role has not faded completely away, however. Important ideas and methods have been adapted from the dynamical systems literature. I believe that chaos has had an impact, though in different ways from those predicted at the onset.

One of several key ideas in chaos is that simple models can generate very rich (and random-looking) dynamics. Implicit in some early work in the social sciences was a hope that simple chaotic models of social phenomena could be matched up with many of the near-random and difficult-to-explain empirical patterns that are observed. This early goal has proved elusive.

One problem is that determining if a time series was generated by deterministic chaos is not easy. (A time series is a data set showing the state of a system over a period of time--a sequence of voting results, for instance, or the fluctuating price of gold.) There is no single statistic capable of being estimated that indicates what is going on in a social system. Also, many common time-series problems (such as seasonality and trends) can confuse most of the diagnostic tools that people use. These complications have led to many conflicting results. Building an easy-to-use test that can handle the intricacies of a real-world time series is a tough problem, one which will probably not be solved anytime soon.

A second difficulty is that most of the theoretical structure in chaos is based on purely deterministic models that have no noise, or at most just a very small amount of noise, affecting the dynamics of the system. This approach works well in many physical situations, but it does not offer a very good picture of most social situations. It is hard to look at social systems isolated from the environment in the way that one can analyze fluid in a laboratory beaker. Once noise plays a major role in the dynamics, the problems involved in analyzing nonlinear systems become much more difficult.

Empirical Successes and Failures: Chaos pushed empirical researchers in many fields to analyze their well-worn data from a new perspective. In the social sciences, economics and finance--fields in which researchers have relatively long, clean data sets to work with--have probably led the group, but there has been some work in other areas.

The early excitement about chaos theory centered on the fact that many of the diagnostics used in physics could be applied to any time series, independent of the theories of what causes it to change. But again, most of these tests were designed for the low-noise worlds of experimental physics. (They also worked best with what is called 'low-dimensional chaos,' meaning they were designed for chaotic systems that themselves were not

too complicated.) Analysis of time series in the social sciences often gave indications of previously unanticipated structure, but few or no strong statements could be made about the sort of low-dimensional chaos studied in physics.

Much interest focused on the role of chaos in finance, because of the abundance of data and the obvious interest in detecting unknown, predictable patterns. Once again, the tests have indicated the presence of enough nonlinear structure to fuel debates about the predictability of stock prices and foreign exchange rates, but definitive statements about chaos lie well beyond what the data are able to tell us. Much of this failure stems from the fact that chaos tests depend on predictability to some extent. Many tests monitor short-range forecasts and the speed at which they degrade. If the degradation happens sufficiently quickly, this behavior can be listed as one of several necessary conditions for chaos. But in financial markets, any observable structure is weak at best, and measuring the precise speed at which a forecast degrades is probably a hopeless task.

Although fitting chaotic processes to social-science data series has proved problematic, certain nonlinear time series tools and techniques inspired by chaos have thrived. Chaos served an important role for empirical researchers, reminding them how much structure in a time series could be invisible to the standard linear diagnostics that were in use 15 years ago. In many fields, both physical and social, time series that were thought to be random, or derived from linear dynamics, have been reanalyzed using new, more powerful diagnostics. In many cases, researchers have found previously unknown, deterministic structures. These structures call into question some existing theories about the analysis of variable systems.

Modeling Potential: On the theoretical side, there is a fairly large common thread that runs through most of the social sciences. In many cases, simple, well-understood models have been shown to exhibit chaotic dynamics. Models for business cycles, democratic voting and arms races, have all been demonstrated to possess the possibility for chaos. These findings have instigated a long process of debate and empirical testing. Typical arguments have centered on whether the models make any sense and whether the parameter values used in the models lie within a reasonable range.

In some instances, researchers have attempted to make empirical estimates, but the basic properties that make chaotic models interesting also make them hard to estimate. Fitting past data is possible, but somewhat dangerous for evaluating and testing models. Few models, if any, have been put to the definitive test of out-of-sample prediction. A powerful test would be an experimental one in which a parameter is slowly adjusted and the resulting dynamics of the system observed. Such experiments have been crucial in fluid dynamics and have even been attempted in population-dynamics studies of beetles, but performing such a test will always be difficult in the social sciences. Therefore, theory has left us with many possible roles for chaos in social systems, but none of these has been rigorously demonstrated to offer a good picture of how the systems really work. (Many of these theories about unusual dynamics actually predate the

'chaos era.' Researchers working on voting theory and business cycles have known that the stability and dynamics of their systems could be badly behaved, or chaotic, for quite some time.)

One recent development in the theory of social systems has been the move away from aggregate, large-scale models. New models inspired by complex systems build social systems from the bottom up; behavior is simulated for individual agents, then taken to the aggregate level either through analytic methods or through explicit computer simulations. This revised approach gives a picture that is far less mechanical than that proposed by the first wave of theory, and uses simpler, better-defined assumptions about small-scale behavior (rather than hoping for some kind of convergence of the macro dynamics to a relatively simple chaotic mapping). This promising area of investigation is only in its early stages, but it will probably become more important in the future.

Policy Questions: Finally, there are important policy reasons for continuing the push to understand the impact of nonlinearities and chaos in social systems. The control of nonlinear systems can actually be easier than the control of linear ones, because it might take only a small push to engender a big change in the system. In other words, small, low-cost policy changes could have a large impact on overall social welfare. On the minus side, it may be very difficult to determine reliably when and where to apply these policies, and how to evaluate their impact.

There are areas where social and physical dynamical systems interact in complex ways. One example of this is the spread of infectious diseases such as AIDS. Understanding the linkages between the nonlinear dynamics of the biological components and the sociological components of such diseases will be crucial to understanding and, hopefully, controlling their spread.

Conclusion: In summary, chaos theory has not yet had as dramatic an impact in the social sciences as it has in the physical sciences. Chaos-based ideas have been very influential, however, both for empirical and for theoretical wings of research. They have forced us to push our data sets harder in searching for time-series structure. They have reminded us of the possibility that some ostensibly well-understood theoretical models may contain a hidden wealth of rich, dynamic structure. Finally, they remind us how humble we should be in our exploits to predict and make policy decisions for large-scale social systems.